Error Budgeting and Certification of Dimensional Metrology tools

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Radiography and ultrasonic inspection have tremendous value in identifying features and defects in physical and biological samples and engineering structures. The historical focus of these inspection methods has been quantitative but without a clear understanding of uncertainty in the measurements. For many applications at LLNL, it would be of significant value to use these inspection techniques as quantitative metrology tools with well understood uncertainties. These could be used to obtain dimensional information on the internal structure of engineered components and assemblies, to be compared to specified tolerances. An example of the latter requirement would be in validating the precision of centering an inner component within an outer shell, which precludes access with a coordinate measuring machine (CMM) or visible light inspection.

In FY2006, we initiated a project to formulate error budgets for key LLNL radiographic and ultrasonic tools that would provide rigorously defined uncertainties in associating dimensional information with their acquired data. Specifically, for the Xradia Micro-XCT (x-ray computed tomography) and the Laser UT (ultrasonic testing) systems, we prepared a framework for error budgets comprising the source, object, and detector.

In Fig. 1 we show how information flows in these systems and where errors can be accumulated.

In this project, we will form predictions of the uncertainty of dimensional measurements for NDE instruments, based on analyzing the physics of the information flow in the instruments and sources of uncertainty. We will also fabricate calibration artifacts that can be measured on other independent instruments, such as CMMs, which have existing uncertainty values for dimensional measurements. In comparing our predicted uncertainty with measurements on pre-characterized artifacts, we will validate our ability to associate uncertainties with dimensional measurements on these instruments.

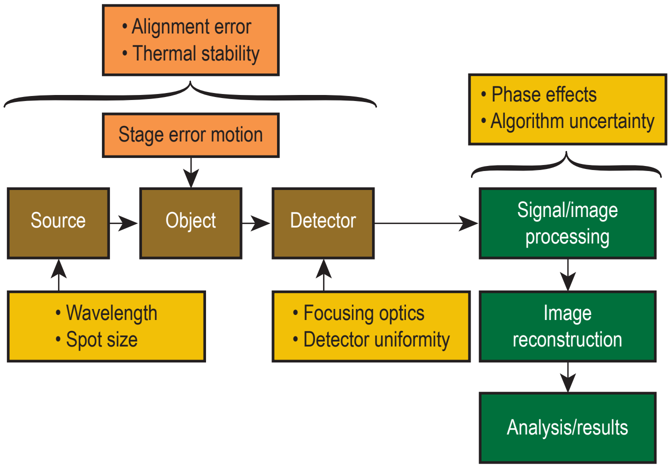

Figure 1. Error diagram showing possible sources of system uncertainty.

Project Goals

The goal is to produce validated quantitative error budgets for the Xradia Micro-XCT and the Laser UT systems, which will enable a structured approach for improving the capabilities of these machines, as well as provide insight into the effect of individual error sources.

Relevance to LLNL Mission

The result of this project will be a broader view of dimensional metrology that extends beyond the traditional tools used in LLNL's precision engineering. Weapons Complex Integration (WCI) and NIF obtain improved quantification of the uncertainties in the fabrication of targets or other components. Both HEDP and ICF target fabrication will benefit from an improved understanding of the measurement uncertainties involved with these metrology tools.

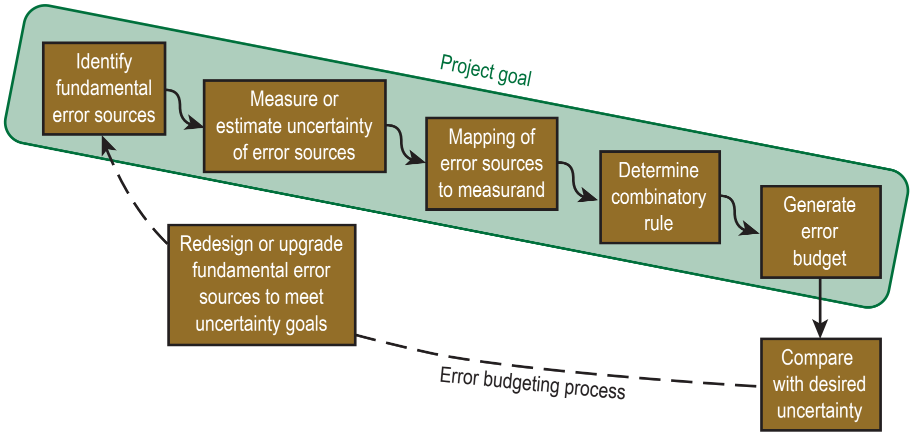

Figure 2. The error budgeting process.

FY2007 Accomplishments and Results

Error budgets for the Xradia Micro-XCT and the Laser UT systems have been produced. Figure 2 shows the project goal of creating validated error budgets for the NDE machines. The feedback portion of Fig. 2 indicates the value in having an error budget to identify key areas of a metrology instrument to gain the most return on investment for upgrades or redesigns.

The Xradia Micro-XCT system consists of multiple sets of stacked axes between the source, object, and detector. Even though the source and detector axes are typically stationary during a CT scan, the thermal, vibrational, and control stability of these axes are directly coupled to the uncertainty in the final CT data. Measurements of positional stability have been made between the source and object as well as between the object and detector.

Typically, the Xradia Micro-XCT system uses only the rotary axis to rotate the object with respect to a fixed source, and the detector to generate 2-D projections (radiographs) for computed tomographic image reconstruction of the object.

The first set of tests performed showed the angular positioning accuracy of the axis. Subsequent tests are being performed to measure the radial, axial, and tilt motion of the rotary axis. Figure 3 shows that an object would move 2.7 µm due to the rotary axis tilt error at a typical fixturing location above the axis. Data from the testing will be used to complete the population of the error budget, which will allow the propagation of these errors through object retrieval algorithms to determine system sensitivity.

Related References

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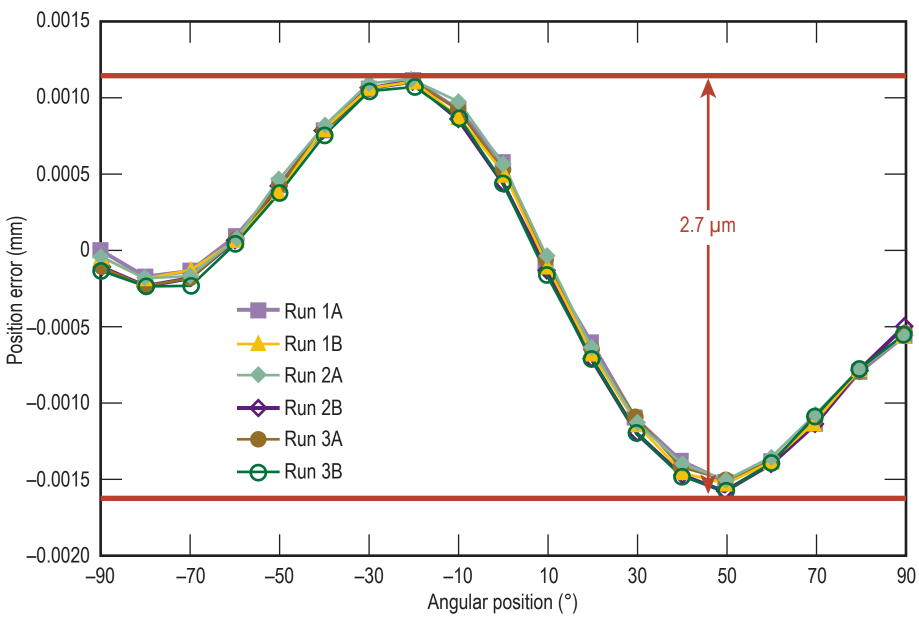

Figure 3. Position error of a part 25 mm above the rotary axis, due to tilt motion of the axis, for the Xradia Micro-XCT.

FY2008 Proposed Work

For FY2008, we will use the sensitivity information from the error budgets to choose characteristic artifacts to validate the error budget predictions. These artifacts will be measured on both CMM and NDE tools to create validated error budgets for the Xradia Micro-XCT and Laser UT. These quantitative error budgets will be used to state uncertainties in dimensional measurements and will lead to improved uncertainties in future generations of these instruments.